Bandwidth enhancement of compact microstrip rectangular antennas for UWB applications

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Abstract

In this paper design of microstrip patch antennas are presented for ultra wideband (UWB) applications. The designed antennas have good matching input impedance in a wide frequency band covering the UWB frequency band which is defined by the FCC. The proposed antennas consist of rectangular patch which is fed by 50Ω microstrip line. These antennas are investigated and optimized by using CST microwave studio, they are validated by using another electromagnetic solver HFSS. The proposed antennas are designed and optimized taking into account the optimized of the ground by using Defected Ground Structure (DGS) in order to improve the frequency band of microstrip antenna. Hence, the impedance and surface current of the antenna structures are affected by DGS. As will be seen, the operation bandwidth of the proposed antennas is from 3 to 15 GHz (return loss≤-10 dB), corresponding to wide input impedance bandwidth (133.33%), with stable omnidirectional radiation patterns and important gain. A good agreement has been obtained between simulation and measurement results in term of bandwidth clearly show the validity of the proposed structures. These antennas are useful for UWB applications, may be able to potentially minimize frequency interference from many wireless technologies i.e WLAN, WiMAX. Details of the antennas have been investigated numerically and experimentally.

Keywords: defected ground structure (DGS), FCC, ultra wideband (UWB), WiMax, WLAN

1. Introduction

Ultra-wideband (UWB) communication technology is becoming very attractive in modern and future wireless communication systems.UWB is increasing rapidly due to the need to support more users and to provide information with higher data transmitting rates as in the multimedia.UWB technology has wide applications in short and long arrange and high speed wireless systems, among this applications, we find medical imaging, ground penetrating radar systems (GPSR), military communication systems, wireless local area net works (WLAN), WiMAX. In 2002, this growth was initialed when the Federal Communication Commission (FCC) of US declares the unlicensed operation band from 3.1 to 10.6 GHz, with a given spectral mask for both indoor and outdoor applications in the USA. This regulation defines UWB radio transmission technology occupies a bandwidth of more than 500 MHz or more than 25% of its center frequency. According to the FCC regulations, the effective isotropic radiated power (EIRP) less than -41.3 dBm/MHz, so the UWB signal has less power than the noise levels. In other words, UWB communication system is based on signal from the low power. This gives rise to the RF signal an inherent immunity to detection which provides high degree of security with low probably of intercept. This recent allocation of a very wide spectrum of frequencies, with low level of power has presented numerous exciting opportunities and challenges for design the UWB antennas [1-4].

From then on, it's necessary to design antenna operated in different frequencies for various wireless transmission functions and operation bands. In recent years, UWB technology has mostly focused to design antenna for wireless communication operate over an ultra wide bandwidth as allocated by the FCC, these antennas should be effective in transmitting, compact, small, and have a good wide impedance bandwidth properties, so that it can be easily integrated with other parts of monolithic microwave integrated circuit (MMIC) designs. Themicrostrip antennas with single or double layer used for UWB applications is increasing for

these reasons low height, compact size, low cost achievement and conformable to planar and non-planar surfaces. In addition to these, they are easy to integrate with other parts of monolithic microwave integrate circuit (MMIC) designs or with mobile wireless systems. It's well-know the microstrip antenna suffers from the narrow bandwidth characteristic; the impedance bandwidth typically limited a few percent 2-5% [5]. the challenge for the implementation of UWB systems is the development of a suitable or optimal antenna.Several researchers exploring RF design of UWB applications. Hence, the first important requirement for the designing an UWB antenna is the extremely wide bandwidth. To meet such requirements, various types of planar antennas have been developed for UWB communications. There have been numerous techniques developed for bandwidth enhancement to overcame this shortcoming, thus to achieve the UWB characteristics. These techniques have been discussed in the literature, for instance, dielectric substrates with high permittivity [6], a planar monopole antenna fed by CPW-fed taped ring slot antenna [7], tuning stub [8]. The printed slot antenna exhibit wider bandwidth, embedding of various slots on the antenna, such as U-shape [9], Z-shaped slot [10] G-slot [11], H-slot [12], they have an attractive property of providing for achieving the UWB antennas.Well as other methods of microstrip elements can also be used to increase the bandwidth [13-16].

Defected Ground Structure (DGS) is one of the methods which are used for this purpose, in order to enlarge the impedance bandwidth of the microstrip antennas, besides to improve its radiation and not requiring additional circuits are for implementation. The DGS is realized by inserted a simple shape defected on a ground plane or sometimes by a complicated shape for the better performance, dependingon the shape and dimension of the defect, which will disturb the shielded current distribution. Furthermore, the defect in a ground will influence the input impedance of microstrip antennas. Therefore, it's one of the technique to reduce the antenna size, to reduce the cross polarization. Also DGS permits to control the excitation and electromagnetic waves propagating all through the substrate. Lastly the DGS in the ground plane plays an important role in microwave circuits and devices to make the system compact, effective and high performance [17-19].

In this paper, an application of the DGS to improve moreover the input impedance bandwidth, toreduce and miniaturise the size of rectangular microstrip antennas are demonstrated. The microstrip antennas with DGS are very suitable for UWB applications. These antenna structures present wide bandwidth and miniaturized dimension and stable radiation patterns throughout of the UWB frequency band.Also the antennasare compact and can cover thewhole frequency band of 5.8GHz-band RFIDsystems, C-band (4–7.5 GHz) satellitecommunications systems, WLAN, ITU, X-bandsatellite communication systems and EuropeanstandardUWB systems. Details of the antenna designs consideration for achieving UWB antennas and both simulated and experimental results are presented and discussed.

2. Destription of UWB Atenna Design
2.1. Rectangular Microstrip Antenna Theory

This section presents the description of the proposed UWB microstrip antenna design and calculations methodology. The antenna structure designed is based on rectangular radiator patch, before designing a rectangular microstrip patch antenna, there are several parameters needed to be considered which will affect the performance of the antenna, whereas the antenna bandwidth andthe resonant frequency. The rectangular patch is the most widely used configuration, for the reason that it can be easily to analyze. The width "W" and length "L" are critical parameters in determining the operating frequencies and input impedance of the antenna.The length of the antenna is about $L=\lambda/2$ for dominant TM_{10} mode. The length of the patch is very critical, it determines the resonant frequency and important that result to the frequency radiated [5].

Hence, to lead to practical designs of rectangular microstrip antennas, there's a design procedure. There are two degrees of freedom (the length and the width) for controlling a rectangular microstrip antenna. The patch width and length should be selected to obtain good radiation efficiency if real state requirements or grating lobe are not overriding factors. The essential parameters for the design are the dielectric constant (εr), the resonant frequency (fr) and height of substrate (h). The procedure is as follows [5]:
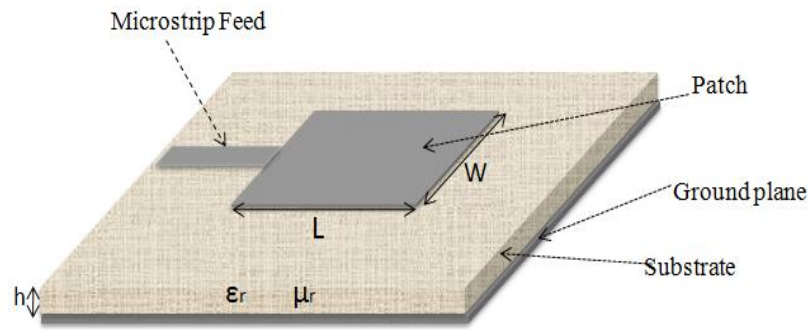
Figure 1. Microstrip rectangular patch antenna

For an efficient radiator, a practical width that leads to good radiation efficiencies is:

$$W = \frac{C}{2\,f_r\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

where C is the free space velocity of light. The length has been extended on each end by a distance ΔL, the length of the patch is:

$$L = L_{eff} - 2\Delta L \tag{2}$$

the effective length of the patch is:

$$L_{eff} = \frac{1}{2f_r\sqrt{\varepsilon_{eff}}\sqrt{\varepsilon_0\mu_0}} \tag{3}$$

normalized extension of the length ΔL is:

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

for a rectangular microstrip patch antenna the effective dielectric constant for any TMmn mode is give by as:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{5}$$

2.2. UWB Antenna Designs

The aimed goal of this study is to improve the operating bandwidth of the basic rectangular patch antenna presented in Figure 1 in order to achieve the UWB characteristics. At the same time the final antenna should be small, compact antenna size and easy to be integrated with (MMIC) designs. To start the design, series of optimization is conducted by using CST microwave studio, they are validated by using another electromagnetic solver HFSS. The Figure 2 shows the geometry and configuration of the final antennas with different positions of the additional patch on the bottom side. The proposed antennas are planar microstrip antennas with ultra-wideband radiation properties. These antennas are fed by a microstrip line with a characteristic impedance of 50Ω on an FR4 substrate with a thickness of 1.6 mm, relative permittivity of 4.4 and a loss tangent of 0.025. The final dimensions of the antenna structures are listed in Table 1. Several techniques have been adopted to acquire large impedance bandwidth. In this work, novel rectangular UWB antennas technique designs with the improvement of the bandwidth are proposed. One technique is the optimized of the ground by using DGS with different positions of the additional patch in ground. Figure 3 presents the evolution of the proposed antennas.
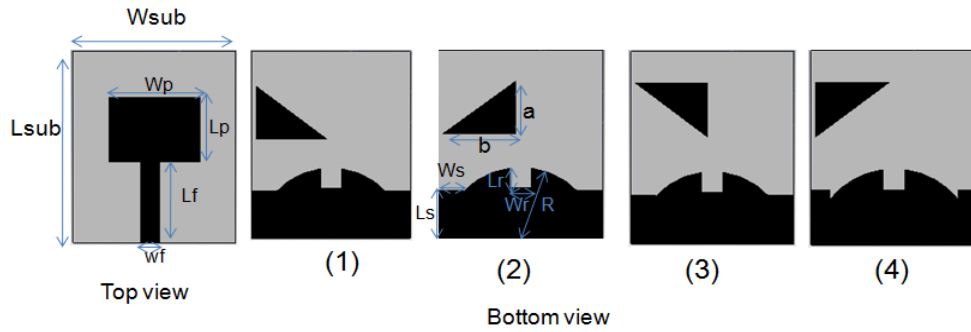
Figure 2. Geometries of the proposed antennas, top view, bottom view with different positions of the additional patch: position 1, 2, 3 and 4
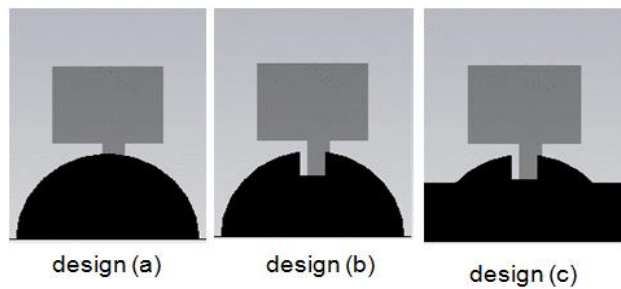

Figure 3. Design evolutions of the proposed antenna

Table 1. Parameters of the Proposed Antennas

Parameter	Value (mm)	Parameter	Value (mm)
Wsub	26	Lsub	30
Wp	16	a	11
Lp	15	b	8.25
Lf	13.25	R	12.2
Wf	3	Wr	3.5
Ls	8	Lr	3.5
Ws	4		

3. Simulation Results andDiscussion

In this section a discussion is given in more detail about the microstrip antennas with defected ground structure (DGS). The reflection coefficient results of the proposed antennas simulated by using the optimization techniques integrated in CST-MW. The reflection coefficient simulation result of all designs of the proposed antenna is shown in Figure 4. Therefore, the first step in designing the antenna, we have started from the design (a). The reflection coefficient of design (a) is showing good matching at the first bandwidth from 3 GHz to 5 GHz, while the second bandwidth is from 5.5 GHz to 8.5 GHz with reflection coefficient less than -10 dB, a semicircular shaped ground with a rectangular notchdefined by (Wr*Lr) and a symmetric rectangular next to the semicircular areprinted in bottom sidehave effect on the enhancement of the impedance bandwidth of the antenna, the design(b) and the design (c),it can be seen that the reflection coefficients were improved.

Eventually, to cover more bands, we have completed the DGS by associating an additional patch. Intensive work has been done to investigate the antenna performance due to different positions of the additional patch. Figure 5 shows the effect of the additional patch for different positions on the proposed antenna in term of the reflection coefficient. We can observe the additional patch has the good effect to improve the bandwidth and to get the best resonant frequencies.
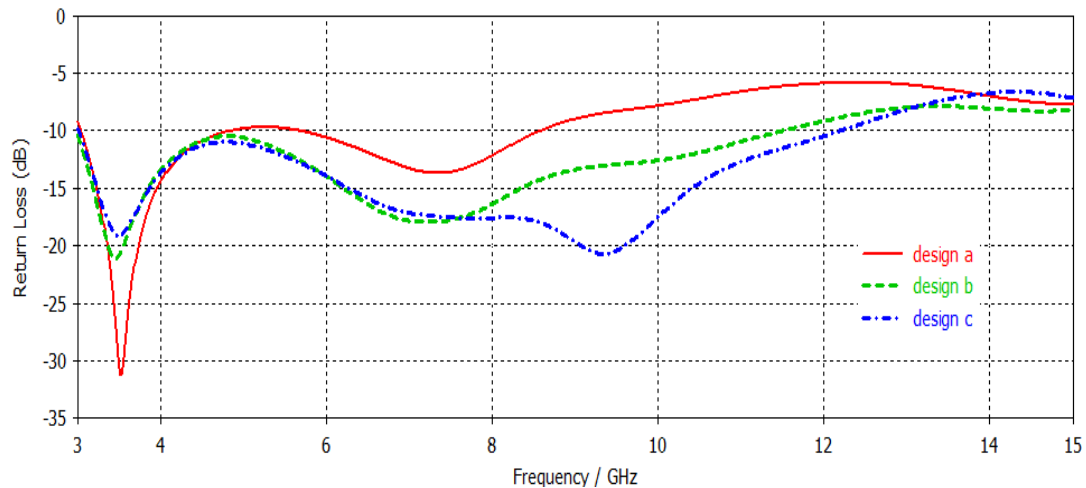
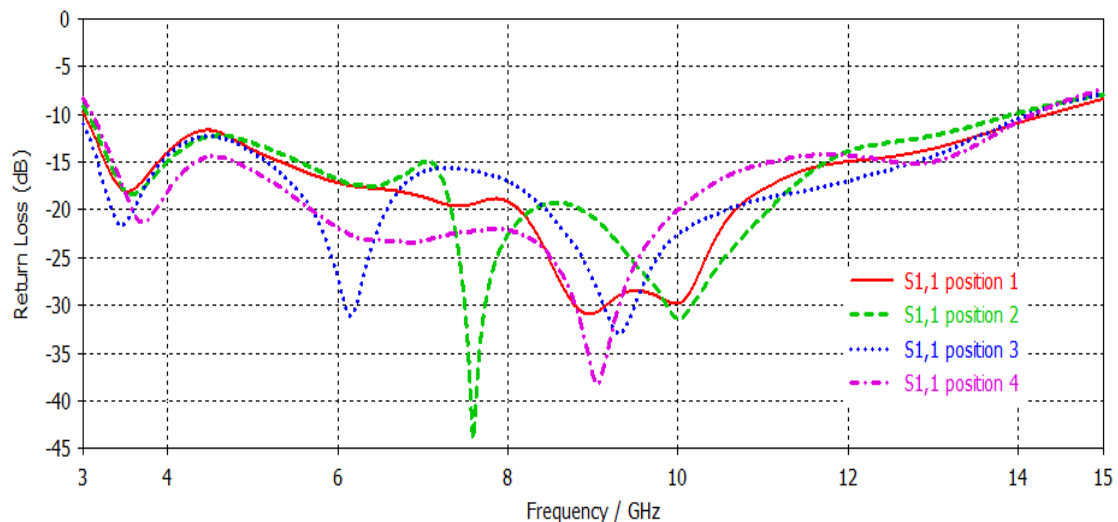Figure 4. Reflection coefficients for different designs of the proposed antennas

Figure 5. Reflectioncoefficients for different position of additional patch of
the proposed antenna

For the validation and the comparison of the results obtained by CST, we have applied another method to analyze these antennas, then we have use the FEM (Finit Element Method) introduced by HFSS software. After the simulation, the following results are shown in Figure 6, it is clearly observed that simulation results on CST and HFSS are closest agreement in terms of bandwidth results. The Figure 7 presents the simulated gain for proposed antennas versus frequency for different values of frequencies along the operating frequency band. It is clearly observed that simulation results provide the maximum gain variation is about 4.9 dBi. The Figure 8 Show the radiation patterns of the proposed antennas at azimuth and elevation planes for different frequencies (3.1 and 10.6 GHz). Generally, the radiation patterns are symmetric and nearly omnidirectional. The radiation is relatively stable along the operating frequency band defined by FCC. On the other hand, in E-plane the simulated results show an almost omnidirectional in low frequencies which is 3.1 GHz and similar to the bi-directional for high frequency which is 10.6 GHz. In H-plane the radiation patterns is quasi- omnidirectional for all frequency bands.
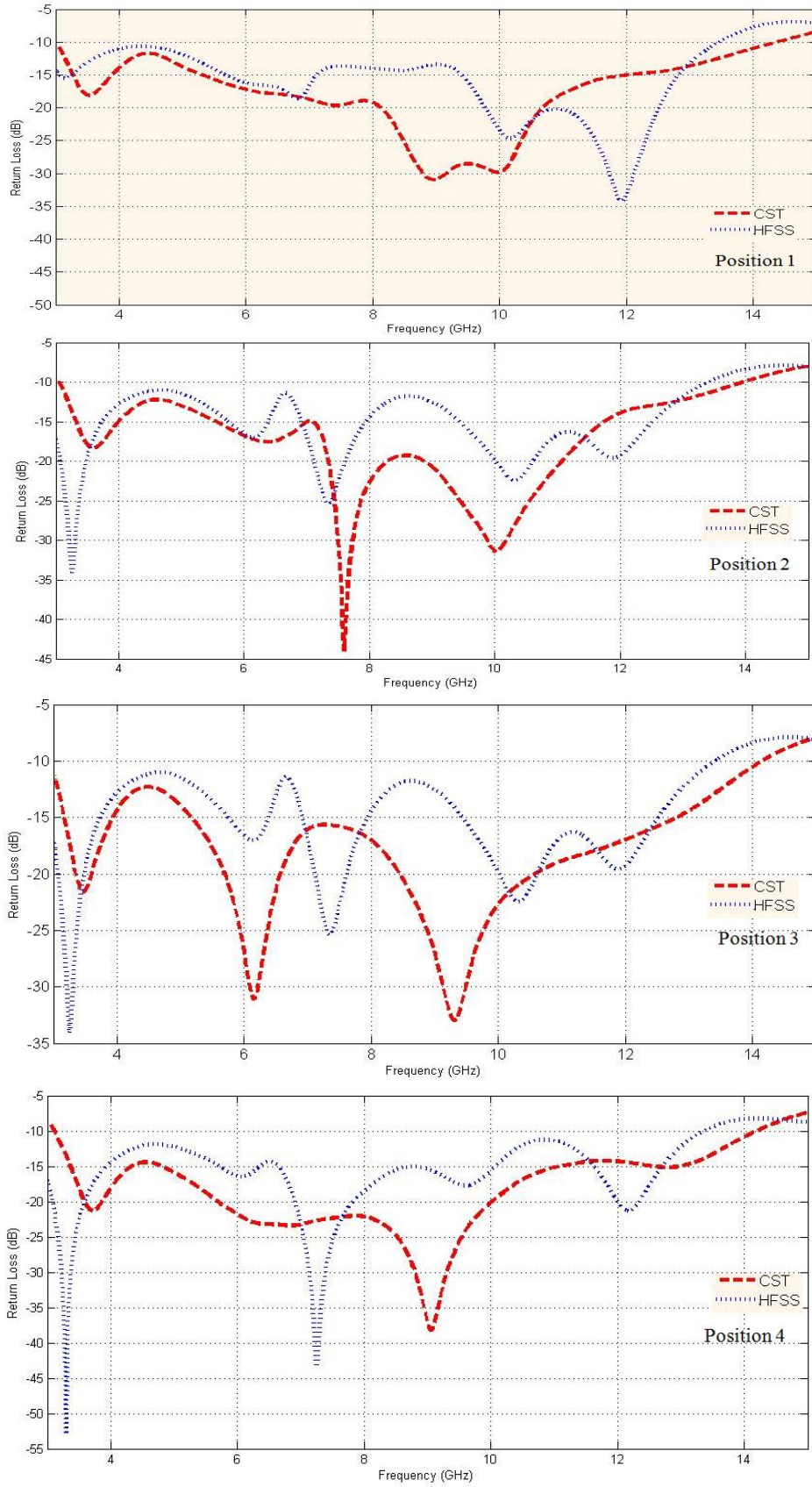
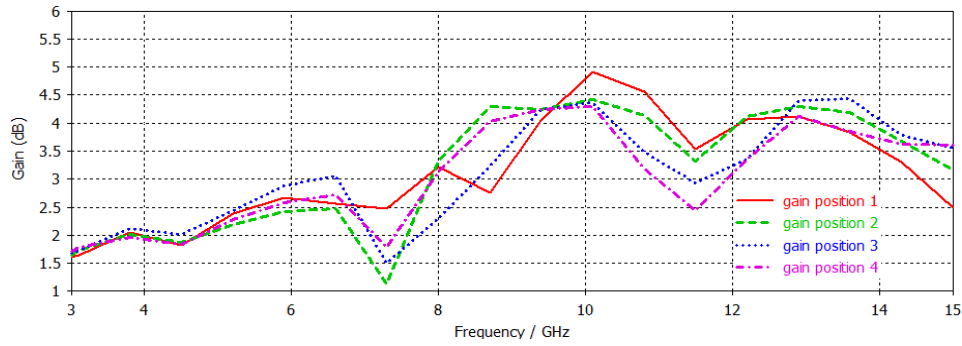Figure 6. Comparison between reflection coefficients obtained by HFSS and CST-MW
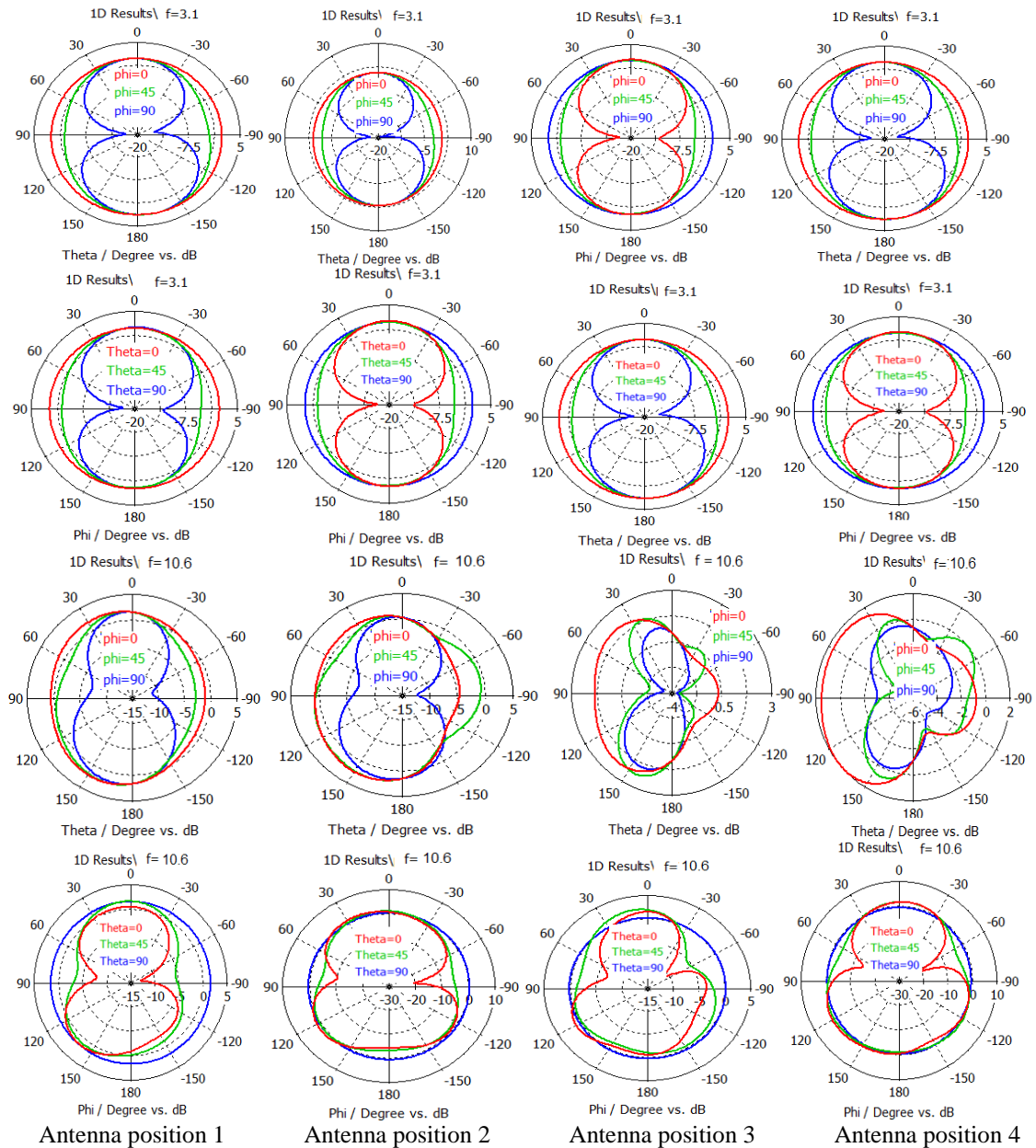
Figure 7. Simulated gain of the proposed antennas

Antenna position 1   Antenna position 2   Antenna position 3   Antenna position 4

Figure 8. Simulated radiation patterns for the proposed antennas on E-plane and H-plane at:
3.1 GHz and 10.6 GHz

4. Achievement and Measurement Results

We fabricated the proposed antennas by using LPKF machine, after the design, optimization by using CST and HFSS. The prototypes of the proposed antennas for different positionsare illustrated in Figure 9. We measured the reflection coefficientusing the Agilent Technologies 2-port PNA-L Vector Network Analyzer N5230A. The calibration used is the 3.5 mm Agilent technologies calibration kit composed from Open, Short and Load components. Figure 10 shows the simulation by using two electromagnetic solvers CST-MW and measuredreflection coefficients results. It can be observed that the measurement is in agreement with the simulation results one across the whole operating band. Besides, the proposed antennas have wideband performance from 3.1 GHz to 14.5 GHz covers the FCC commercial UWB band with a fractional bandwidth of 139%.These type of antennas can easily be integrated with RF/microwave circuits for compact design and fabricated at a very low manufacturing cost.
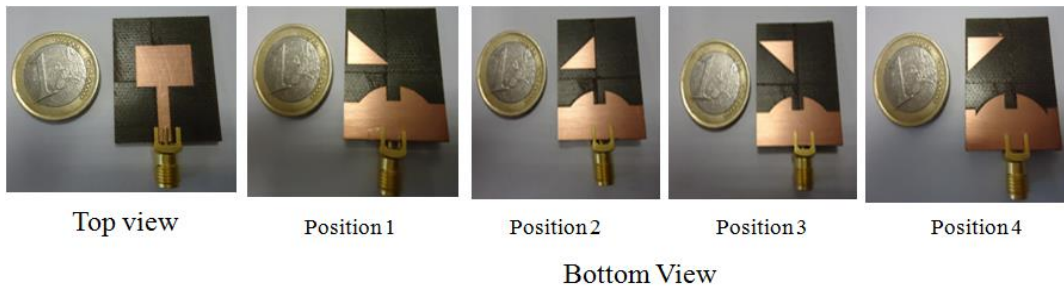

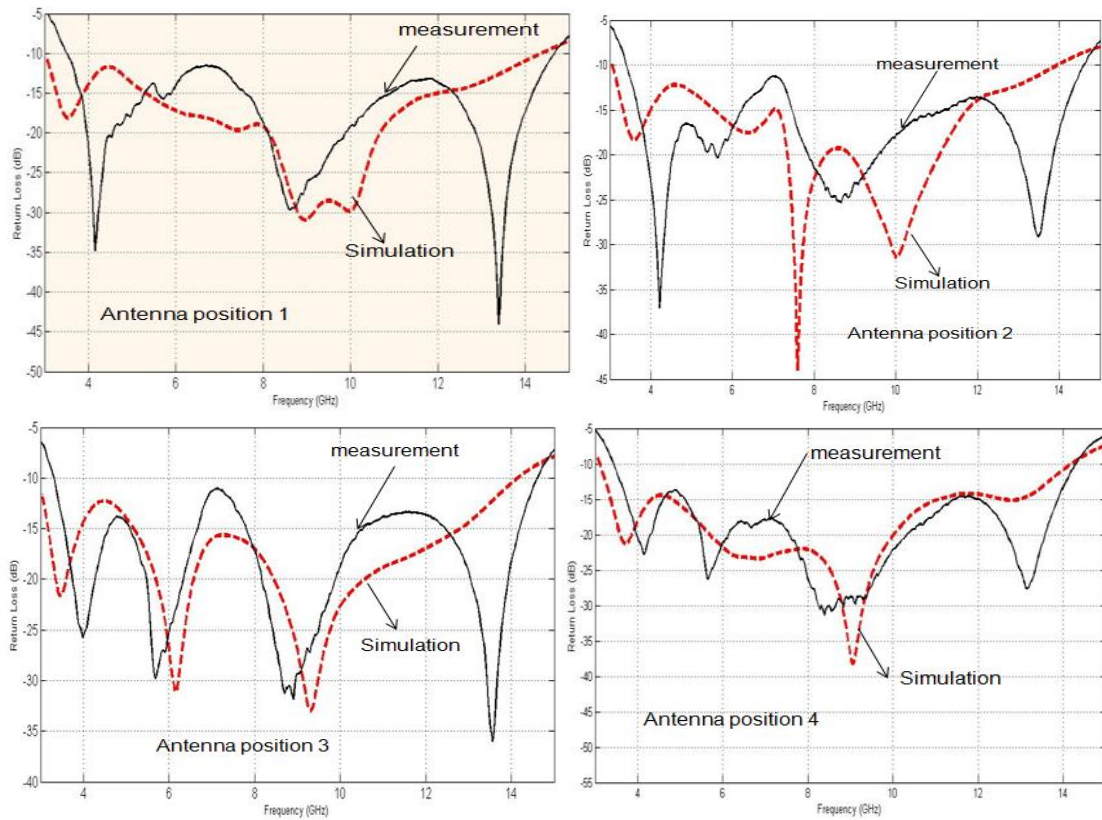Figure 9. Photographs of the achieved UWB antennas

Figure 10. Simulated and measured reflection coefficients vs frequency of the proposed antennas

This measurement was done by using a 50 Ω SMA (Surface Mount Adaptor), which is connected to the end of the microstrip transmission-line and grounded to the ground plane. However some disagreement between the simulated and measured results are observed. One of the reasons is that the measurement of a small antenna is very sensitive to the presence of the RF cable connected to the input of the antenna, creating an additional inductance. Another reason, the substrate FR4 used for the fabrication of these antennasdoes notposses uniform characteristics in terms of its material properties.This gives rise to degradation of antenna performance. Table 2 presents the summaries the performances and compares the proposed antennas to recently published UWB antennas.

Table 2. Comparison between Recently Proposed Antennas and these Antennas

References	Substrate material	Methode for improve bandwidth	Operating bandwidth	Structure Size (mm^2)	Gain (dB)
[19]	FR4	Patch with two steps and a circular slot with partiel ground	3.5-16 GHz	30x31.5	Not reported
[18]	RT-Duroid	Double I Slot	7.2-12GHz	34.2x29.2	2-3.5
[17]	FR4	Finger-Shaped	3-12GHz	40x35	2-6
[11]	FR4	Tuning stub	3-11.5GHz	28x21	2-7
[20]	FR4	Defected ground structure	4.2-12GHz	11x16	Not reported
Proposedwork	FR4	Defected ground structure	3.5-14.5GHz	26x30	1.5-4.8

5. Conclusion

A novel small compact rectangularpatch antennas have been designed; simulated and fabricated forUWB applications. We showed that by embedding an additional patchwith a proper dimensions and with differentpositions in theground plane, a wide impedance bandwidth from 3.5 to 14.5 GHz (11 GHz) with S11<-10dB isachieved. The measurement results show goodagreement with simulation in term of bandwidth. Therefore, these antennas are suitable candidates for UWB bands applicationsand can easily be integrated with RF/microwave circuits for compact design and fabricated at a very low manufacturing cost.

Acknowledgements

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